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DEVELOPMENT AND USE OF A LINEAR MOMENTUM EXCHANGE DEVICE

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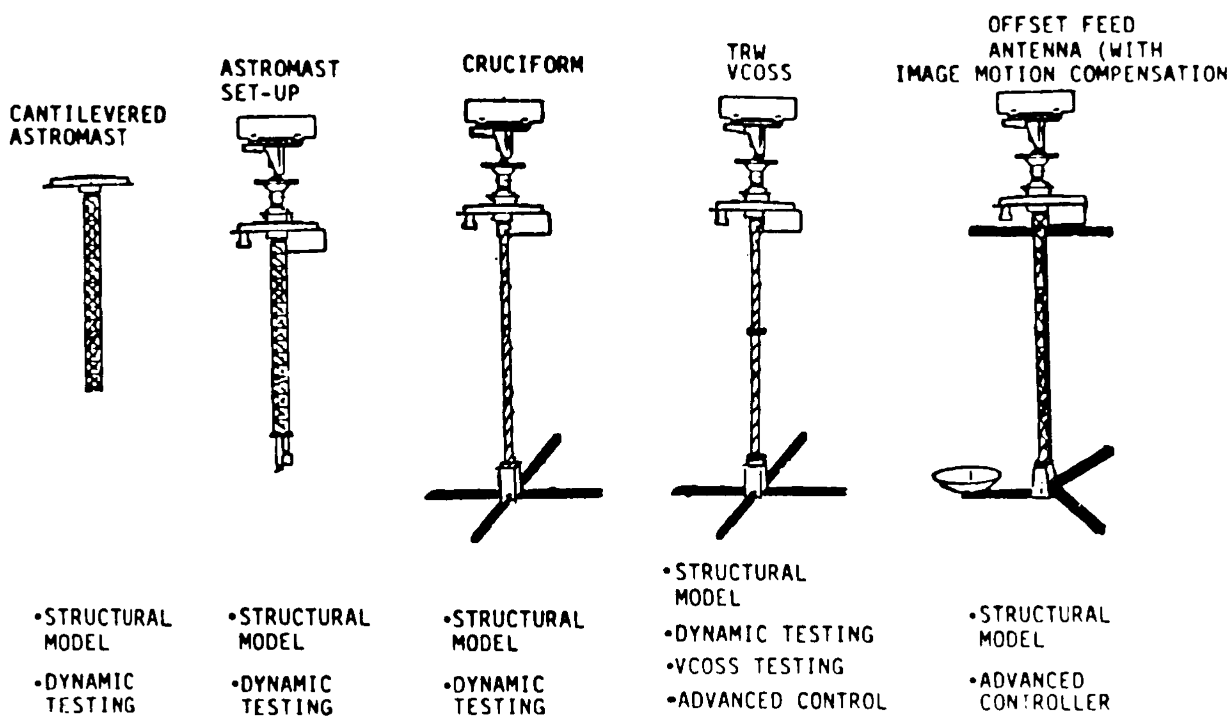
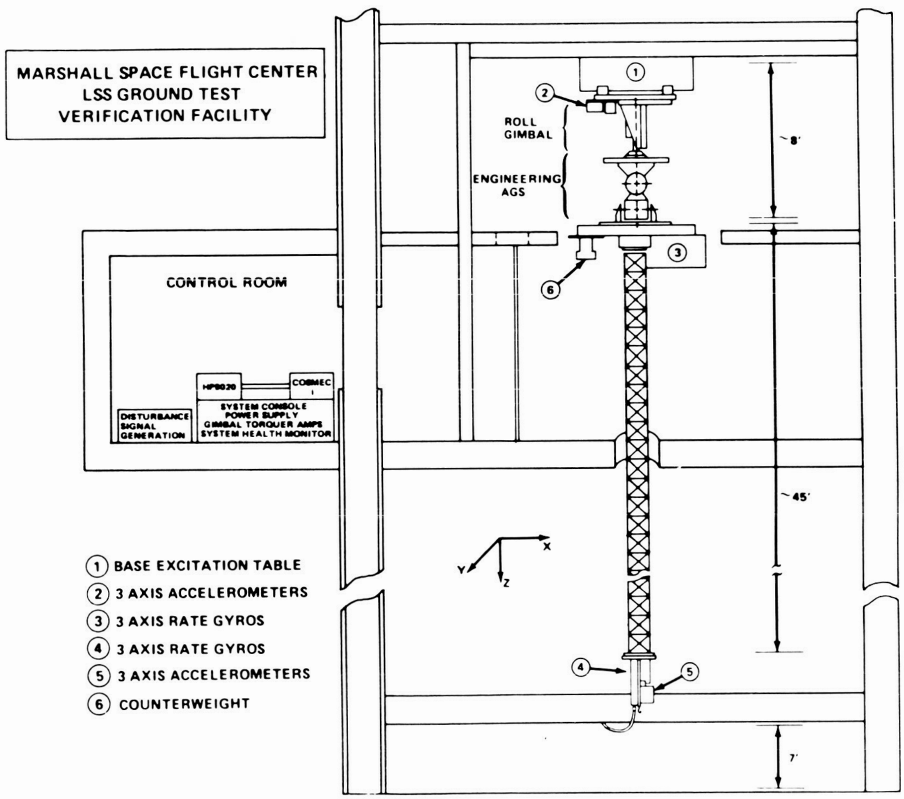
Program Summary

In 1981 the Marshall Space Flight Center (MSFC) began establishing an in-house facility for testing control concepts to be applied to Large Space Structures (LSS). As shown below the original concept called for a long flexible beam suspended from the ceiling by a low friction support system. The lower end of the beam was to be mounted to the Advanced Gimbal System (AGS). Analysis and system engineering soon showed that a more tenable design would be where the whole system was inverted, i.e., the AGS hung from the ceiling with the beam hanging down from it. While this configuration, augmented by a base excitation table (BET) was being built, an ASTROMAST obtained from JPL was extended, analyzed and tested. From that basic configuration has evolved the cruciform, VCOSS and ACES configurations as shown in the figure. The addition of the cruciform added low frequency nested modes and the additional instrument package at the tip contains gyros to monitor tip motion.



The figures below serve to show some details of the facility. The artists' figure shows the placement of the BET, the AGS (with a MSFC added third gimbal), the gyros mounted on the AGS faceplate and the beam tip instrument package. The control room, which is adjacent to the test area, contains the gimbal drive electronics, the data acquisition electronics, a Hewlett Packard 9020 computer augmented by an Analogic Vector Processor and outgoing command electronics. At the present time the system can handle 64 incoming signals and 48 outgoing channels. The present length of the beam is forty-five feet. However, the facility is capable of accommodating beams of one hundred and twenty feet in length. The photograph was taken by a camera located at the top of the beam underneath the AGS faceplate.



The program evolved to the point in 1985 where it was desired to test distributed sensors and actuators. An agreement was reached between the Air Force Wright Aeronautical Laboratories (AFWAL) and MSFC in which AFWAL contracted with TRW to supply four channels of linear momentum exchange devices (LMEDs). Each LMED included a collocated linear accelerometer so as to implement the sensor/actuator portion of the positivity control concept. In addition, an engineering unit, which was used as a stimulus (one channel), was supplied without an accelerometer. Additional equipment supplied under the contract included an optical measuring system to determine the beam position at each LMED with respect to the laboratory frame. The concept of the LMED is to exchange momentum between the vibrating beam and the LMED proof or seismic mass. The system energy is dissipated in the action of the electrical forcing circuitry. In the cases tried so far, the proof mass has been driven with a velocity signal derived from the collocated accelerometer. One of the pictures below shows an assembled LMED mounted to the ASTROMAST, the other shows a disassembled LMED (engineering unit).

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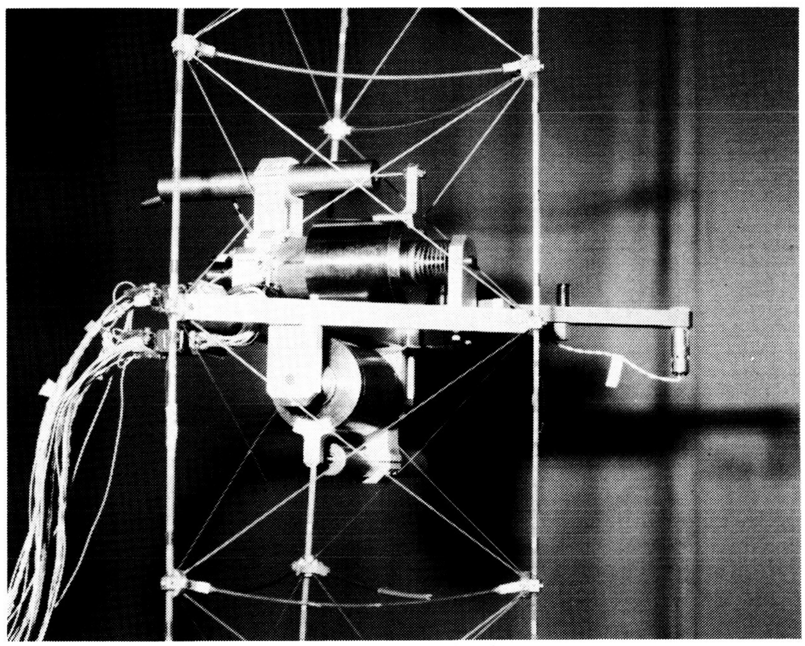
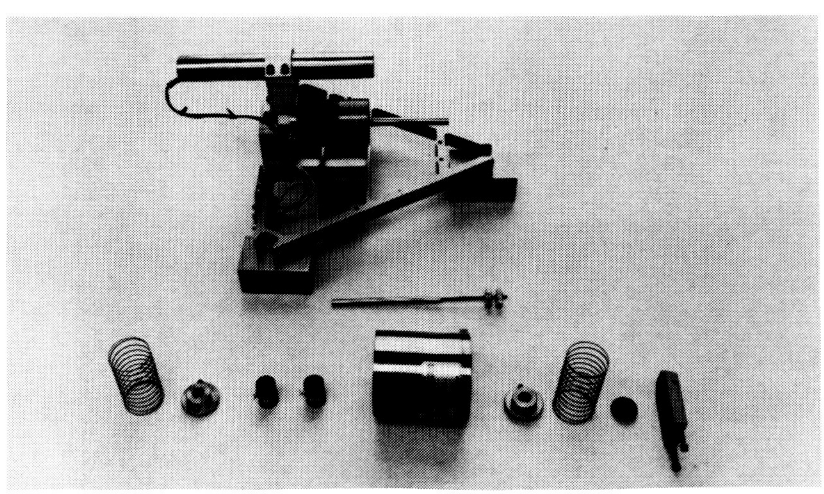
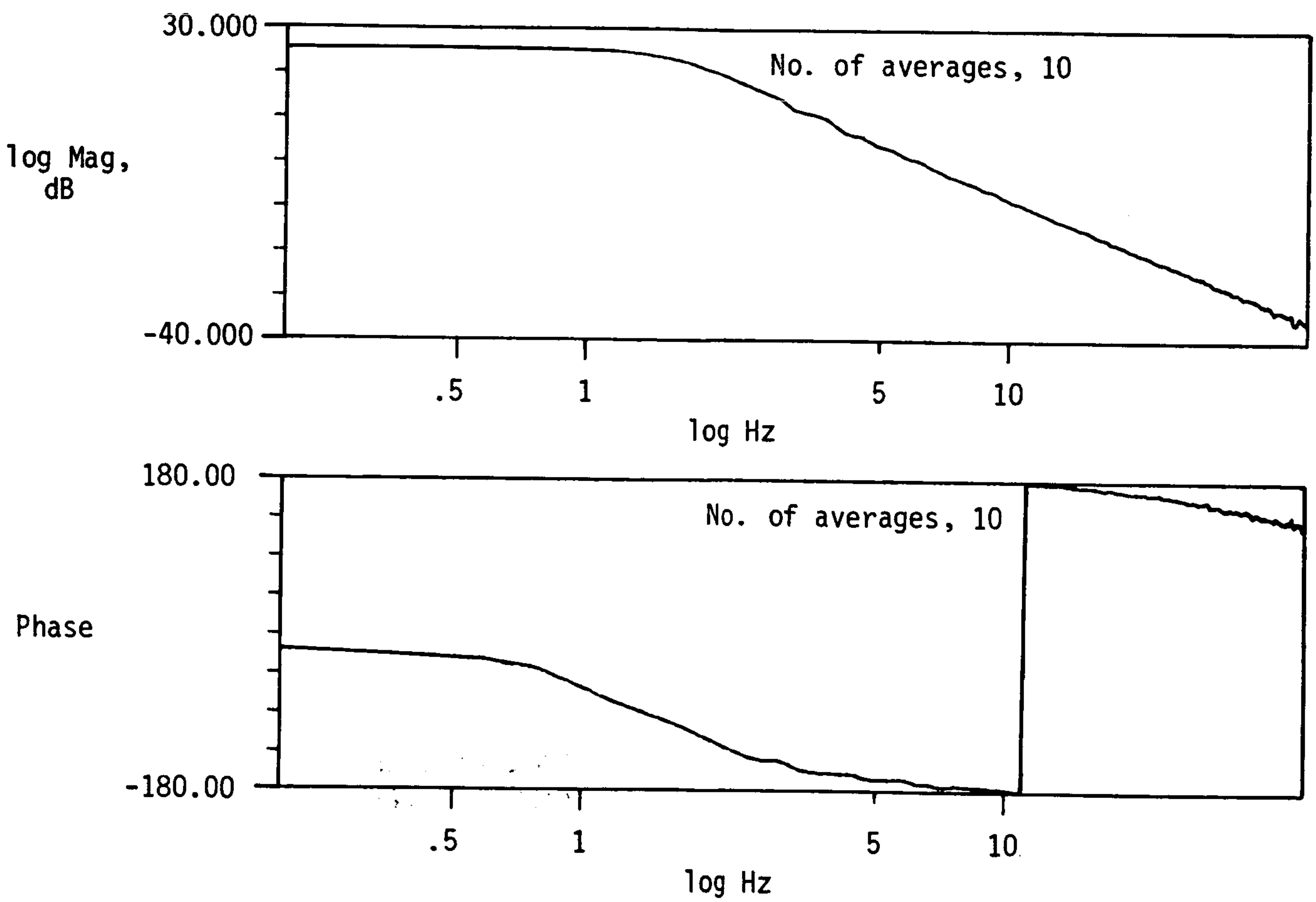




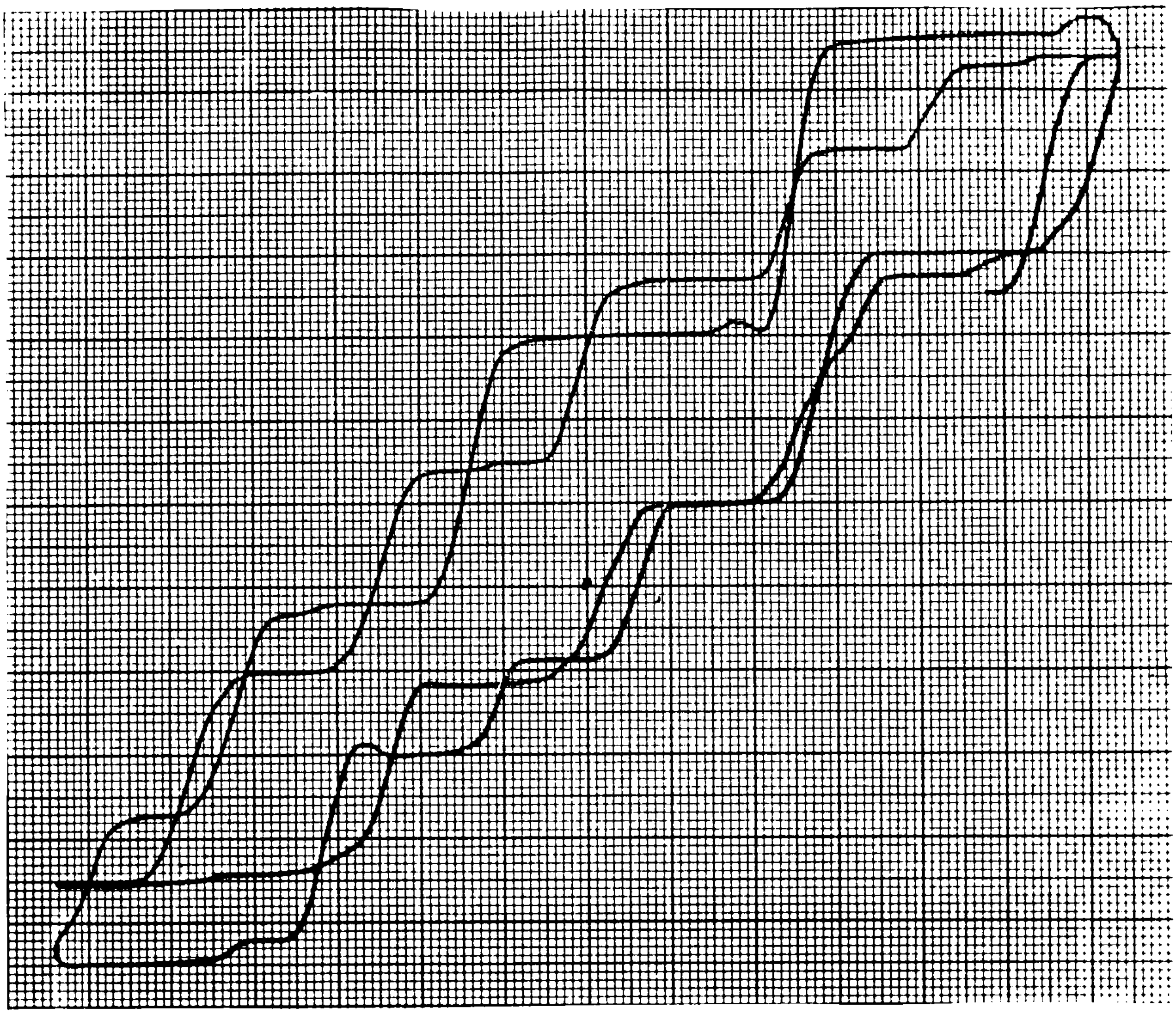
After the LMEDs were delivered, a number of component tests were run at MSFC. These tests consisted of frequency response and hysteresis curve generation tests. To generate the frequency response curves the linear motor drive amplifier was excited with wide-band noise and the resulting motion of the seismic mass was measured by the output of the linear voltage differential transformer (LVDT) that came with each LMED. This LVDT output was processed by an analyzer and produced a typical curve as shown. From this curve it can be deduced that the device's response was probably more than critically damped. To generate the hysteresis curve a sine wave was impressed on the linear motor amplifier and this voltage along with the LVDT output voltage was impressed on the x and y input channels of a recorder. A typical hysteresis curve is also shown. It was noted that as the frequency of excitation increased, the jerking or steplike characteristic of the LMED hysteresis tended to decrease.

Typical LMED Frequency Response from Volts into Power Amp to Volts Out of LVDT



Typical LMED Hysteresis Curve

LVDT Output Voltage 5.5 Volts p-p Where 20 Volts=
1 Inch Displacement of Proof Mass



Power Amp Input 0.2 HZ Sine Wave (0.3 Volts p-p)

Study of the frequency response and hysteresis curves as well as physical inspection of the LMEDs showed that a product improvement program needed to be undertaken. Accordingly, the engineering LMED was disassembled, inspected and cleaned. This inspection disclosed that all elements of the seismic mass suspension, i.e., the shaft, springs, bearing and balls, were magnetic. It also disclosed that there were surface imperfections in the shaft. Accordingly, new matched instrument bearings were ordered as were matching steel shafts. This matched set has palpably tighter specifications than the originals even though they were a one-to-one substitution physically. While waiting for the new bearing and shaft combination to arrive from the vendor, MSFC fabricated a shaft to loose specifications. Use of this shaft with the original and new bearings confirmed that surface finish influenced highly the grabbing or steplike characteristics of the hysteresis curve. This conclusion was heightened when the new steel shaft arrived and was tried. The hysteresis was diminished greatly by constructing a hard anodized aluminum shaft to the same basic specifications as the special order steel shaft. Even though the balls were still magnetic, there was a dramatic decrease in the area of the hysteresis curve. The modification sequence is listed below.

Modification Sequence

1) original system - Thompson Super-4 bearings with polished steel shaft

2) Thompson Super-4 bearings with low magnetism stainless steel shaft

3) Barden LS4 bearing with original and low magnetism shafts

4) Thompson 4812-SS bearing with original and low magnetism shafts

5) Thompson Inst-4812-SS instrument grade bearing with matching polished steel shaft (4 micron surface finish).

6) Thompson Inst-4812-SS with anti-magnetic shaft (hard anodized aluminum, 2 micron surface finish).

At the conclusion of the modification sequence previously described, new frequency response and hysteresis curves were run. Typical results are shown. The frequency response curves show that damping has been reduced from something over critical to the neighborhood of 0.2. Going hand-in-hand with this measurement is the fact that if one displaces the seismic mass from its equilibrium position and then releases it, the mass oscillates a number of times about the equilibrium position whereas before because of friction it did not. When viewing the hysteresis curves, one has to be extremely careful of the scales. If one plots the curves corresponding to the aluminum shafts on the same scale as the original curves, they would appear to be straight lines. Some numerical feel for this may be gained by defining a gain as the ratio of seismic mass deflection to drive voltage of the linear motor. In the case of the original bearing-shaft combination a typical number might be 18. For the modified units a value of 355 is typical.

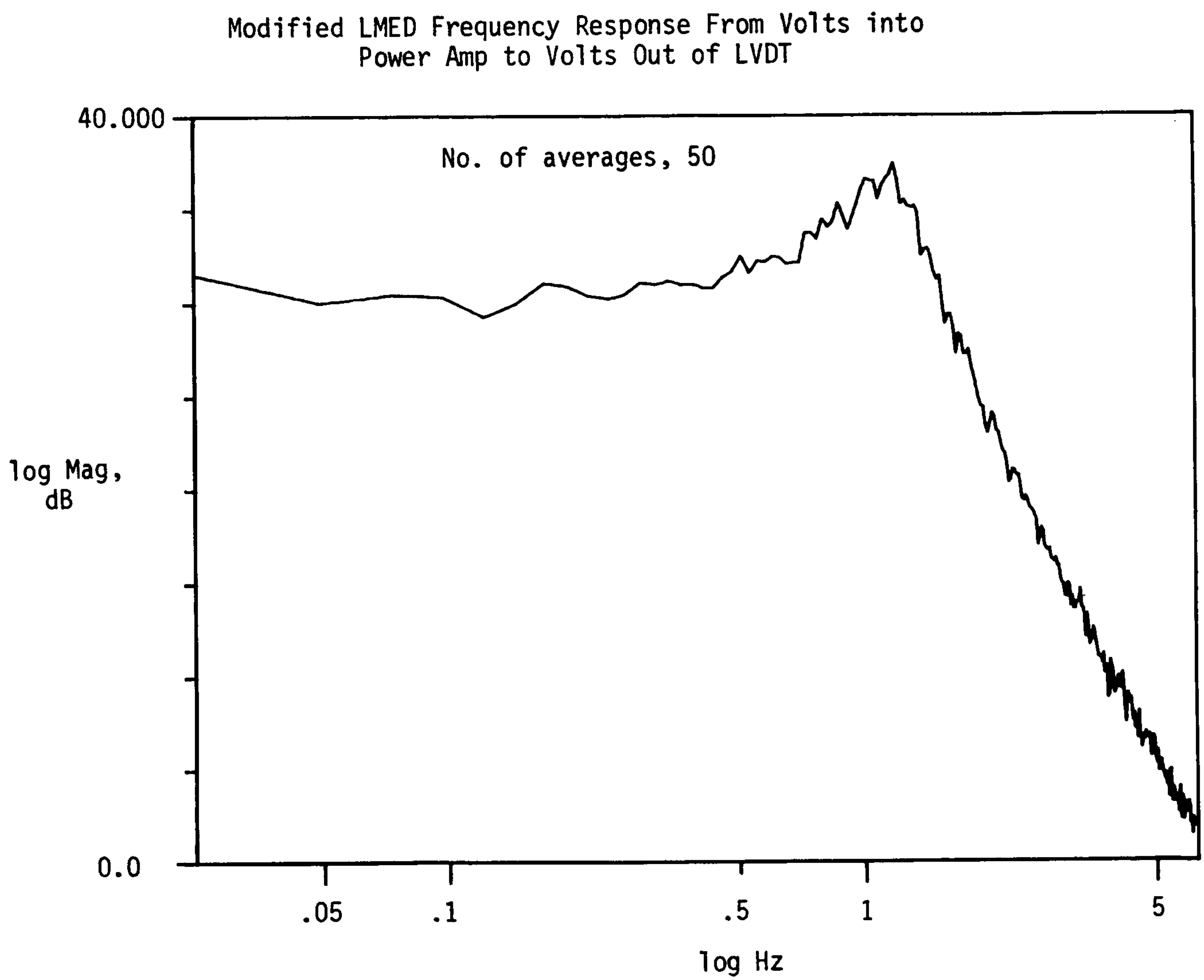
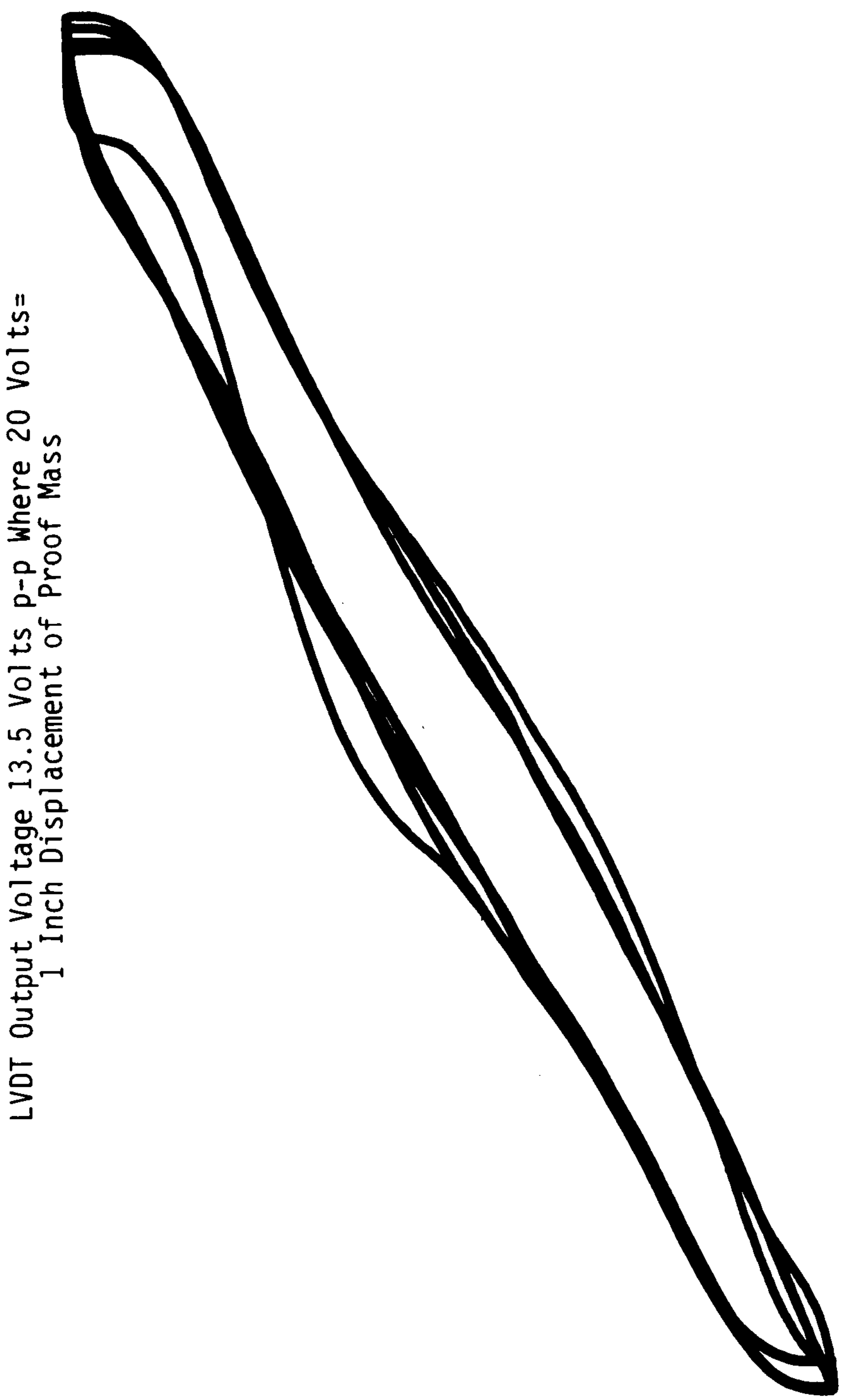


Figure 6

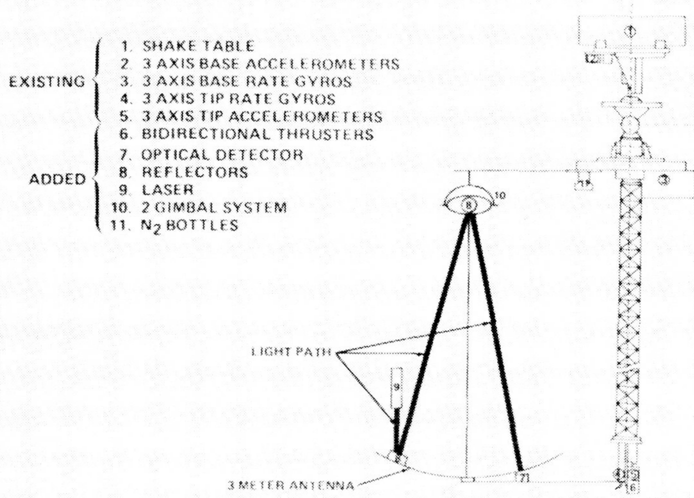
Modified LMED Hysteresis Curve



Power Amp Input 0.2 Hz Sine Wave (0.038 Volts p-p)

During the time period of the next AFWAL-MSFC program called Active Control (Technology) Evaluation for Spacecraft (ACES) the MSFC LSS structures/control test facility will be maintained in the ACES configuration. In this configuration the modified LMEDs as discussed above will be mounted on the structure. Also on the structure will be a laser excited beam steering subsystem incorporating a small two gimbal table for articulating the steering mirror. This configuration has a sensor complement of 6 gyro channels, 4 accelerometers (on LMEDs), 2 gimbal pickoffs on the two gimbal table and optical detector systems to measure 2 laser beam deflections and deflections of the mast at the LMED stations relative to the laboratory frame. It has 5 driven gimbals and 4 LMEDs for use as actuators. Thus, it is ready for use as a universal test bed for a number of control laws that have been developed.

STRUCTURES/CONTROLS TEST FACILITY CONFIGURATION 2



TECHNIQUES TO BE DEMONSTRATED

- ACTIVE IMAGE MOTION COMPENSATION
- VIBRATION CONTROL VIA LINEAR THRUSTERS
- EVOLUTIONARY CONTROL
- CLOSED LOOP PARAMETER ESTIMATION/CONTROL

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